

Performance analysis of PVT

4.1 Energy analysis

When dealing with energy balances, we usually refer to the first law of Thermodynamics, which states that energy is a conservative property; this means that during any real steady-state process the overall energy flow leaving a system equals the overall energy flow entering the system, Fig.4.1.

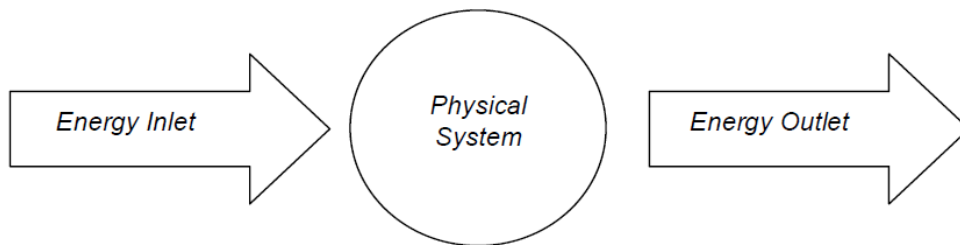


Figure 4.1 Energy flows across a physical system

Actually, the different forms of energy (thermal, mechanical, internal, potential, kinetic) may individually undergo quantitative changes, but the overall amount of energy is conserved. The energy balance equation, which quantifies the energy conservation law for a stationary process observed through a control volume, may be stated as follows:

$$\dot{Q} - P = \sum_{outlet} \dot{m}_k \left(h + gz + \frac{w^2}{2} \right)_k - \sum_{inlet} \dot{m}_k \left(h + gz + \frac{w^2}{2} \right)_k \dots\dots\dots(4.1)$$

Where:

\dot{Q} = thermal energy flow crossing the system boundaries (W).

P = mechanical power crossing the system boundaries (W).

\dot{m} = mass flow rate entering / leaving the system (kg/s).

z = height of the system above a reference level (m).

w = mass flow velocity (m/s).

h = specific enthalpy measured at the system inlet and outlet (kJ/kg).

The index of performance derived from such an approach compares the amount of energy required by the final user (either electric, or mechanical, or thermal...) to the total amount of energy exploited by the system, expressed as:

$$\text{Energy efficiency: } \eta = \frac{\text{Energy released to the user}}{\text{Energy provided to the system}} \dots\dots\dots (4.2)$$

One must realize that such a definition compares different forms of energy. As an example, in the case of a power plant for the production of electric energy, the energy efficiency is defined as:

$$\eta = \frac{P}{Q_{th}} \dots\dots\dots (4.3)$$

Where P is the electric power, and Q_{th} the thermal energy to drive the system.

But, as a matter of fact, different forms of energy have different potentials to produce useful work. So the definition of efficiency stated above is a comparison between quantities which are metrically homogeneous but *not* conceptually equivalent.

4.2 The Second Law of Thermodynamics:

The Second Law of Thermodynamics may help overcome this drawback, on the basis of a rather different approach to system analysis. The starting point is that real processes are not reversible and give rise to entropy production: friction, hysteresis, molecular or thermal diffusion are the most common examples of irreversibilities occurring in a real process. The mathematical form of the Second Law most suitable for our purposes is the Clausius equation:

$$\sum_{outlet} (\dot{m} \cdot s)_k - \sum_{inlet} (\dot{m} \cdot s)_k = \sum_j \left(\frac{\dot{Q}}{T} \right)_j + \sigma \dots\dots\dots (4.4)$$

Where: s = entropy per unit mass (kJ/ (kg/K)).

Q = heat transfer occurring through the system boundaries (W).

T = temperature of the environment being involved in the heat transfer (K).

σ = overall entropy production due to irreversibility (W/K).

The reader is reminded that, as stated by the Second Law, $\sigma \geq 0$, being $\sigma = 0$ only for ideal (reversible) processes.

This relationship is precious to us, as it allows the assessment of entropy production σ , which is always the unknown of the problem.

It is intuitive that when dealing with complex systems, it is possible to decompose them into several, more simple subsystems; by evaluating σ for each one of them, it is possible to detect the ones most responsible for thermodynamic drawbacks and thus provide corrective measures.

The Gouy-Stodola equation:

Let us realize that the first law contains a term for work, but no term for irreversibility, whereas the second law contains a term for irreversibility but not for work.

In order to state a more general equation than the previous ones, let us combine the first and the second law statements. Before doing this it is appropriate to adopt the following expressions:

$$Q = Q_o + \sum_j Q_j$$

$$\frac{Q}{T} = \frac{Q_o}{T_o} + \sum_j \frac{Q_j}{T_j} \quad \dots\dots\dots(4.5)$$

Q_o being the heat transfer to the environment and T_o its temperature. By combining equations (4.1) and (4.4) and taking into account eq. (4.5), one obtains the Gouy-Stodola equation:

$$P = \sum_n \dot{Q}_n \cdot \left(1 - \frac{T_o}{T_n}\right) + \sum_{\text{Inlet}} \dot{m}_k \left(h - T_o s + \frac{w^2}{2} + g z\right) - \sum_{\text{Outlet}} \dot{m}_k \left(h - T_o s + \frac{w^2}{2} + g z\right) - T_o \sigma$$

$$\dots\dots\dots(4.6)$$

For an ideal reversible process ($\sigma = 0$), the Gouy-Stodola equation yields:

$$P_{id} = \sum_n \dot{Q}_n \cdot \left(1 - \frac{T_o}{T_n}\right) + \sum_{\text{Inlet}} \dot{m}_k \left(h - T_o s + \frac{w^2}{2} + g z\right)_k - \sum_{\text{Outlet}} \dot{m}_k \left(h - T_o s + \frac{w^2}{2} + g z\right)_k \quad (4.7)$$

For all real processes $\sigma > 0$, thus $P_{id} > P$, in other terms

$$P_{id} - P = \sigma T_o > 0 \quad (4.8)$$

This means that irreversibilities erode the thermodynamic potential of the energy flows; in other words, at the end of the process or at the system outlet, the energy flows have a lower potential to produce work, and this reduction is measured by the entropy production σT_o . This term is also referred to as “Irreversibility”:

$$I = \sigma T_o$$

4.3 The dead state

The work potential of a system at a given state may be assessed by letting the system proceed towards and actually reach a stable equilibrium with the environment. In fact, when the system and the environment are in equilibrium, no further change of state can occur spontaneously and hence no further work can be produced.

When such a situation occurs, the system is said to be in the dead state. Specifically the dead state is characterized by conventional values for pressure p_o and temperature T_o . Additional requirements for the dead state are that the velocity of the fluid stream is zero ($w_o = 0$) and the gravitational potential energy is zero ($z_o = 0$). These restrictions of pressure, temperature, velocity and elevation characterize the restricted dead state, associated with the thermomechanical equilibrium with the environment. It is restricted in the sense that the chemical equilibrium with the environment is not considered, that is the control mass is not allowed to pass into or react chemically with the environment. The problem of the chemical equilibrium with the environment will be dealt with later on.

4.4 The concept of Exergy

Exergy is defined as the work potential of a system relative to its dead state.

Following this definition, for each term appearing in eq. (4.6), it is possible to derive an expression for exergy. So we have:

Exergy of (mechan. or electrical) work P: $E_P = P$

Exergy of heat Q available at temperature T:

$$E_Q = Q \left(1 - \frac{T_o}{T}\right)$$

Exergy of a mass flow:

$$E_m = \dot{m} \left[(h - h_o) - T_o(s - s_o) + \frac{w^2 - w_o^2}{2} + g(z - z_o) \right]$$

So for a control volume, eq.(0.5) may be rewritten in terms of exergy, as follows :

$$(E_P)_{out} - (E_P)_{in} = (E_Q)_{in} - (E_Q)_{out} + (E_m)_{in} - (E_m)_{out} - \sigma T_o$$

And rearranging the terms:

$$(E_P + E_Q + E_m)_{in} = (E_P + E_Q + E_m)_{out} + \sigma T_o$$

Therefore:

$$\sigma T_o = \sum_{in} E_j - \sum_{out} E_k \quad \dots\dots\dots(4.9)$$

The irreversibility can then be quantified as the difference in exergy measured at the inlet and outlet sections of the control volume.

4.5 Exergy and Anergy

Let us consider a given amount of thermal energy Q available at the temperature T Thus:

$$E_Q = Q \left(1 - \frac{T_o}{T}\right)$$

E_Q can be thought of as the maximum work which can be extracted from a Carnot cycle, receiving the heat Q and working between the temperatures T and T_o .

By rewriting the equation in the form:

$$E_Q = Q - \frac{T_o}{T} Q$$

It is easy to recognize Q as the amount of energy available at the beginning, and $Q \cdot (T_o/T)$ as the amount of energy rejected to the environment as thermal waste; at these conditions, energy is no longer recoverable for technical purposes. Some Authors refer to this quantity as “not available energy” or Anergy.

Similar considerations can be made in relation to the mass flow, where:

$$\text{The exergy is: } (h - h_o) - T_o(s - s_o) + \frac{w^2 - w_o^2}{2} + g(z - z_o)$$

$$\text{The energy is: } (h - h_o) + \frac{w^2 - w_o^2}{2} + g(z - z_o)$$

$$\text{The anergy is: } T_o(s - s_o)$$

All forms of energy at the dead state are anergy. The natural environment is an infinite reservoir of anergy. Distinction should be made between anergy and irreversibility. The former has always existed, the latter results while a process is occurring. Irreversibility is anergy which arises whenever a physical event takes place.

Anergy may enter the control volume and then grow by addition of the irreversibilities. Eventually the anergy flow will join the irreversibility flow, so that at the system outlet the anergy results higher than it was at the inlet.

To summarize the previous results, the following relationship can be stated between energy, exergy and anergy:

$$\text{Energy} = \text{Exergy} + \text{Anergy}$$

A pictorial view of the concepts outlined so far is provided in Fig. 2. Its message is clear: going through the physical system, the exergy flow is lowered by the entropy production, the anergy flow increases by the same quantity, while the energy flow remains constant.

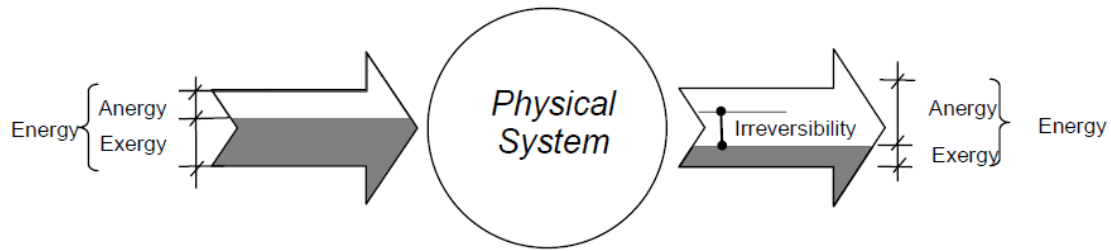


Figure 4.2 Exergy and anergy flows across a physical system

In conclusion, by using the exergy and anergy concepts, the first and second law of thermodynamics may be reformulated as follows:

1. In any process the sum of exergy and anergy remains constant
2. In any real process the exergy decreases and the anergy increases by the same quantity as the entropy production.
3. The anergy cannot be converted into exergy.

4.6 Exergy efficiency:

According to this approach, the thermodynamic figure of merit for a process in a second law perspective is the exergy efficiency, defined as:

$$\text{Exergy Efficiency: } \xi = \frac{\text{Exergy Output}}{\text{Exergy Input}}$$

In formulas:

$$\xi = \frac{E_{out}}{E_{in}} = \frac{E_{in} - \sigma T_o}{E_{in}} = 1 - \frac{\sigma T_o}{E_{in}}$$

The exergy efficiency is thus a ratio between quantities that now are both metrically and conceptually homogeneous. The numerical values of ξ never exceed unity. The maximum exergy efficiency ($\xi = 1$) is only achievable by ideal systems ($\sigma = 0$).

In order to perceive how different the exergy approach is from the energy approach, and how surprising the results are sometimes, the problem of heating and cooling will be discussed in the following section in a very basic way.

4.7 ENERGY EFFICIENCY vs. EXERGY EFFICIENCY in short:

A comparison between energy efficiency and exergy efficiency in the following table:

Table 4.1 Energy Efficiency vs. Exergy Efficiency

Energy efficiency	Exergy efficiency
<ul style="list-style-type: none"> • Takes into account only the 1.st Law • Compares metrically but <i>not always</i> conceptually homogenous term • Is always $\eta > 0$ • but in some cases is $\eta > 1$ (Inverse cycles, heat pumps...) 	<ul style="list-style-type: none"> • Takes into account the 1.st and 2.nd Law • Compares metrically <i>and</i> conceptually homogenous terms • Is always $1 > \xi > 0$ • without exceptions

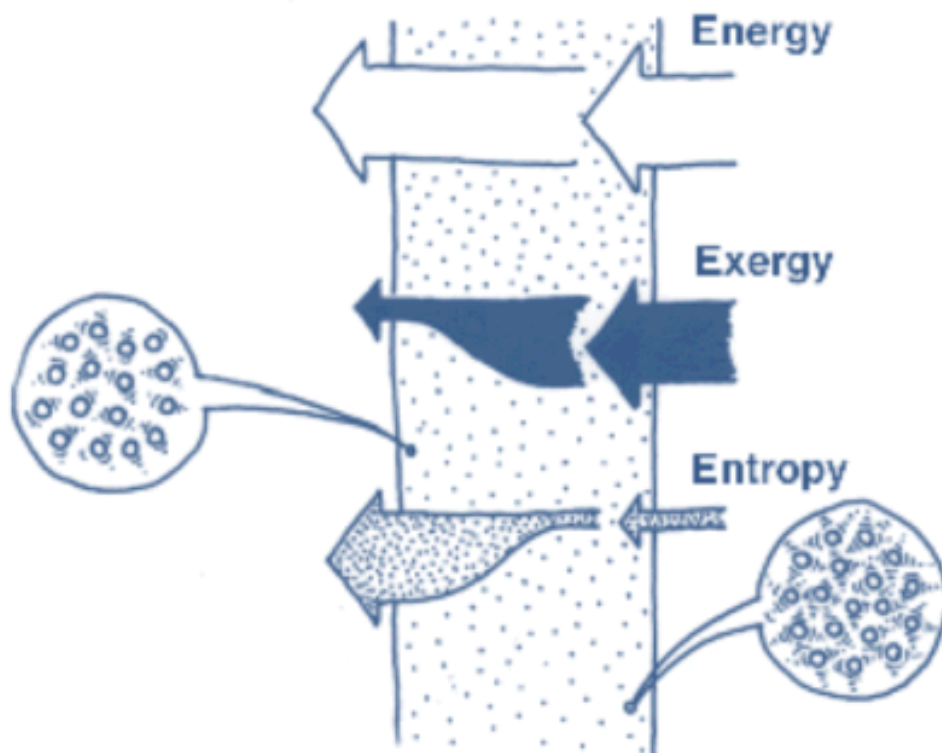


Figure 4.3 Energy , Exergy & Entropy

4.8 Hybrid Photovoltaic-Thermal Module (I3A214-235P)

In this project will be the chosen system is the following:

(I3A214-235P) is a new generation module that combines electrical and thermal energy production. The photovoltaic module is combined with an aluminum collector that directs the exceeding heat, generated from solar radiation and from the normal operation (Joule effect), to a fluid that flows in the collector.

4.8.1 Properties

This system is particularly suitable for those that want to install a photovoltaic system with high performance and need for thermal energy (sanitary water, domestic heating, etc.).

Using a hydraulic connection with a heat exchanger and a water tank, The hybrid system will preheat the water supply to the boiler or to an under floor heating system; moreover it can heat swimming pools and like.



Figure 4.4 The module of PV/T

4.8.2 PV module: characteristics

- Module manufactured with 60 C6BA high-efficiency poly-crystalline Silicon cells, produced in Italy by Helios Technology.
- New 3 bus bar cells that allow a considerable increase in the average module power output.
- Long term stability of the electrical performances, by utilizing first-quality raw materials only and crystalline silicon technology
- 5 W output power tolerance only, in order to minimize the mismatch losses.
- Great spectral response and excellent behavior under low irradiances Thanks to an advanced cells and modules production technology
- New mounting system framework that allows greater regularity and precision.

Of the distances between the sides and diagonals of the module

- Resistance to snow/wind load certified for the module's fixing both in long side or short side.
- Redesigned Junction Box with cables and fast connectors suitable for Any kind of configuration.
- Frame with holes for optical fiber of the Helios Technology antitheft system.

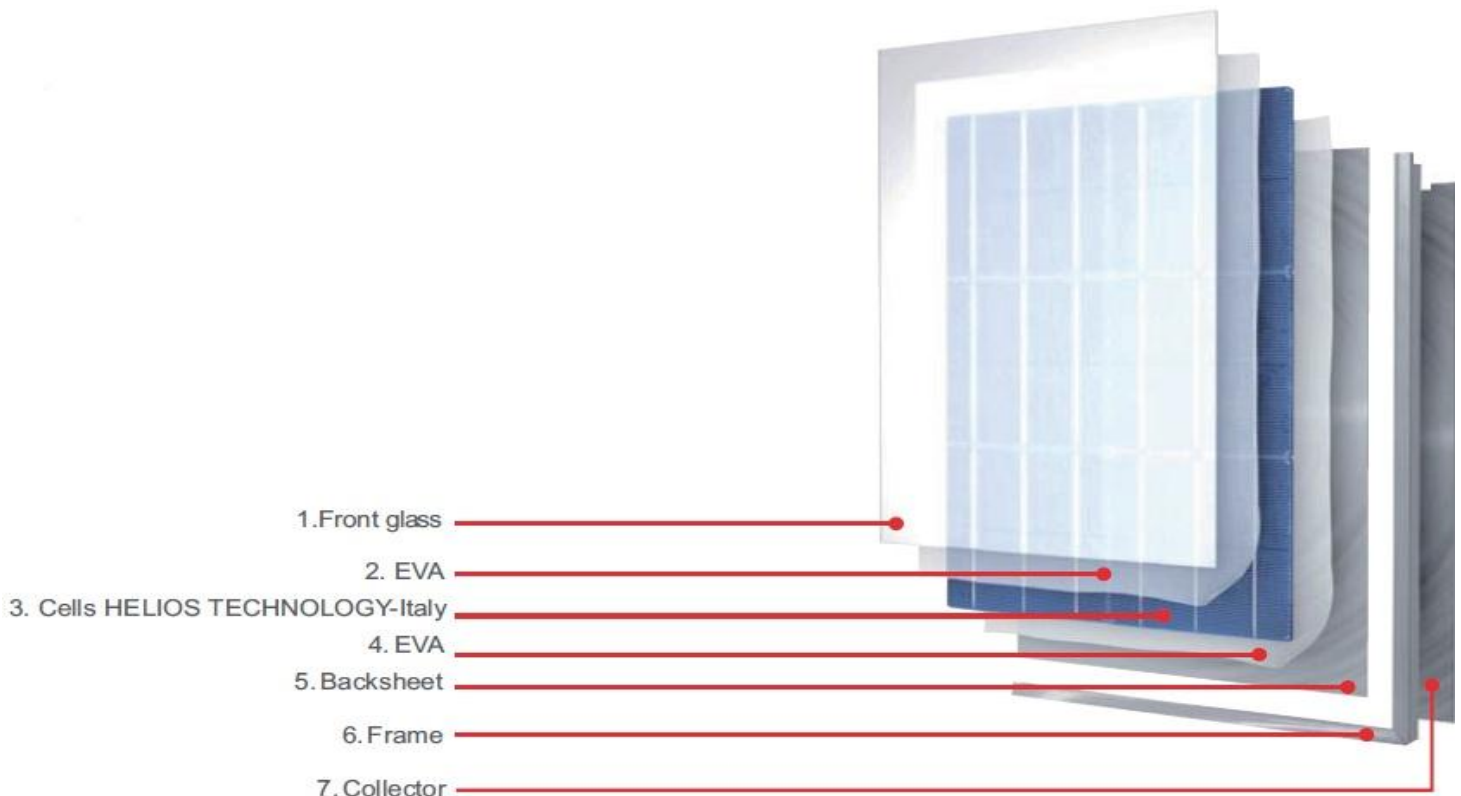
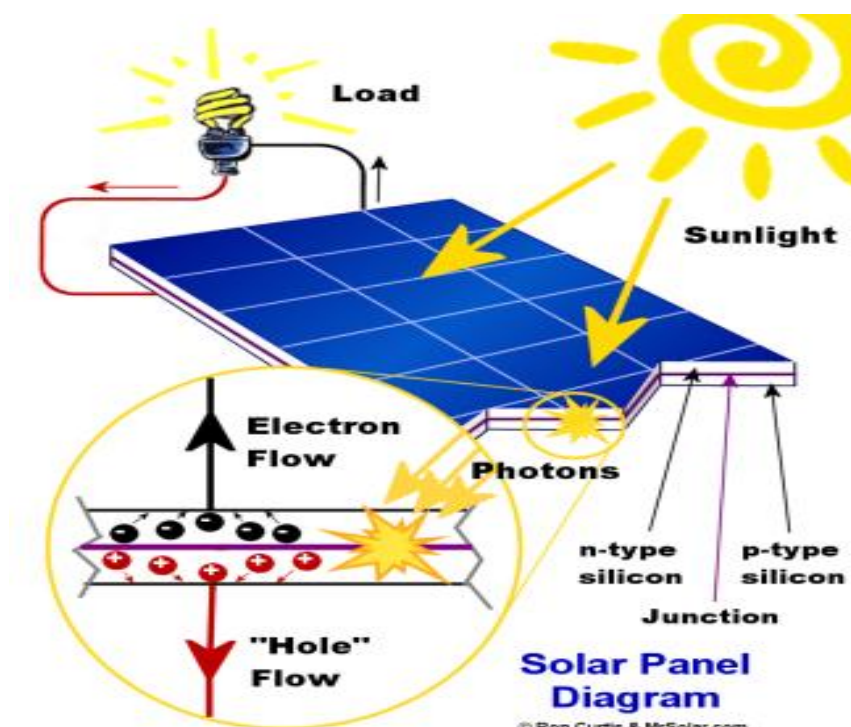


Figure 4.5 Parts of PVT module

4.8.3 Certifications and warranties

- UNI EN 12975/6.
- CEI EN 61215 (2006) for heavy wind - snow loads.
- CEI EN 61730-1-2 (2007) Safety Class II up to 1000 VDC.
- 10 years warranty on defective materials and workmanship for PV components.
- Output power warranty: $\geq 90\%$ in 10 years and $\geq 80\%$ in 25 years.



4.8.4 Physical characteristic

The physical characteristics of the model such as length, width, thickness and other characteristics scheduled in the following table:

Table 4.2 Physical characteristic

MODULE	WITH FRAME
Length	1650 ± 1 mm
Width	990 ± 1 mm
Thickness	38 mm
Front Glass	Low Fe content glass 3,2 mm
Encapsulant	EVA (Ethylene-Vinyl Acetate)
Backsheet	Polyester based multi-layer
Frame	Anodized Al 6060 T5 - 15 µm
Junction box	Tyco® or Compel®, IP65, with 3 by-pass diodes
Connection cables section	1,2 m with two Tyco® or Compel® connectors, 4 mm ²
Thermal collector	Aluminium, designed by Helios Technology 1595 x 935 x 1,5 mm

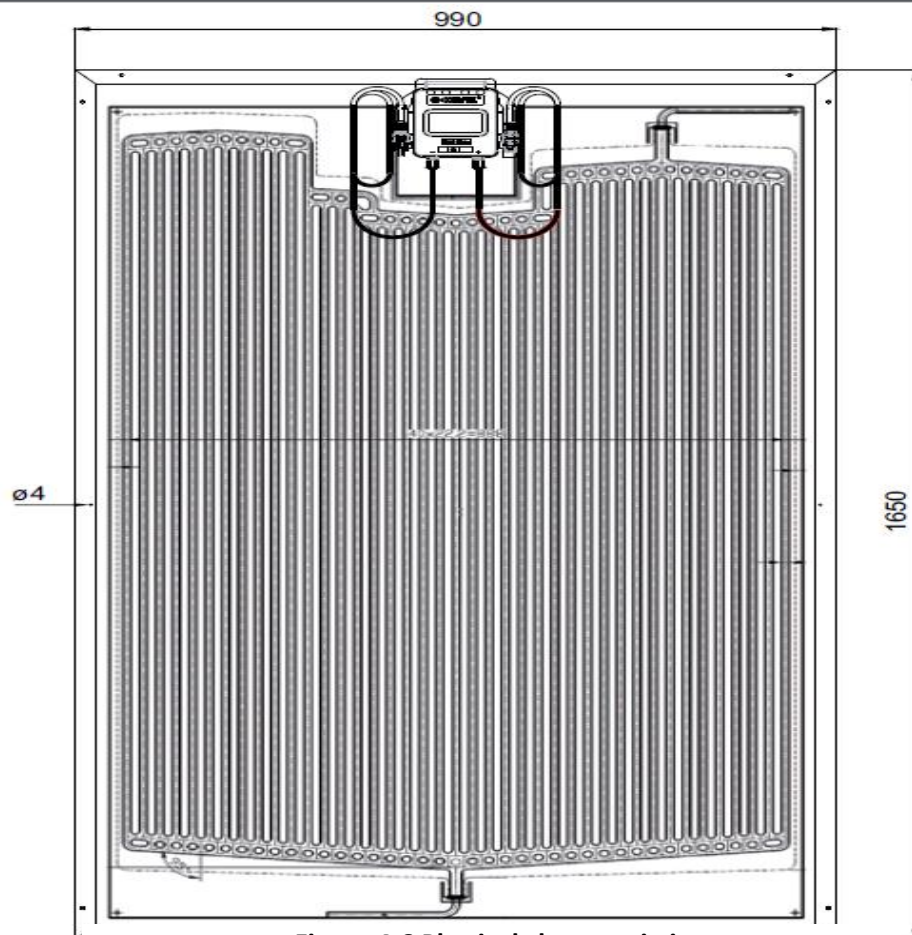


Figure 4.6 Physical characteristic

4.9 Photovoltaic - thermal system main components

- (I3A214-235P) hybrid module.
- Tank for the hot water produced by the system.
- the hydraulic circuit: it transfers the heat from the module to the tank and from this one to the users inside collectors flows a never-freezing fluid).
- An electrical circuit, which includes a pump for water and a temperature control unit, normally used in solar thermal field.

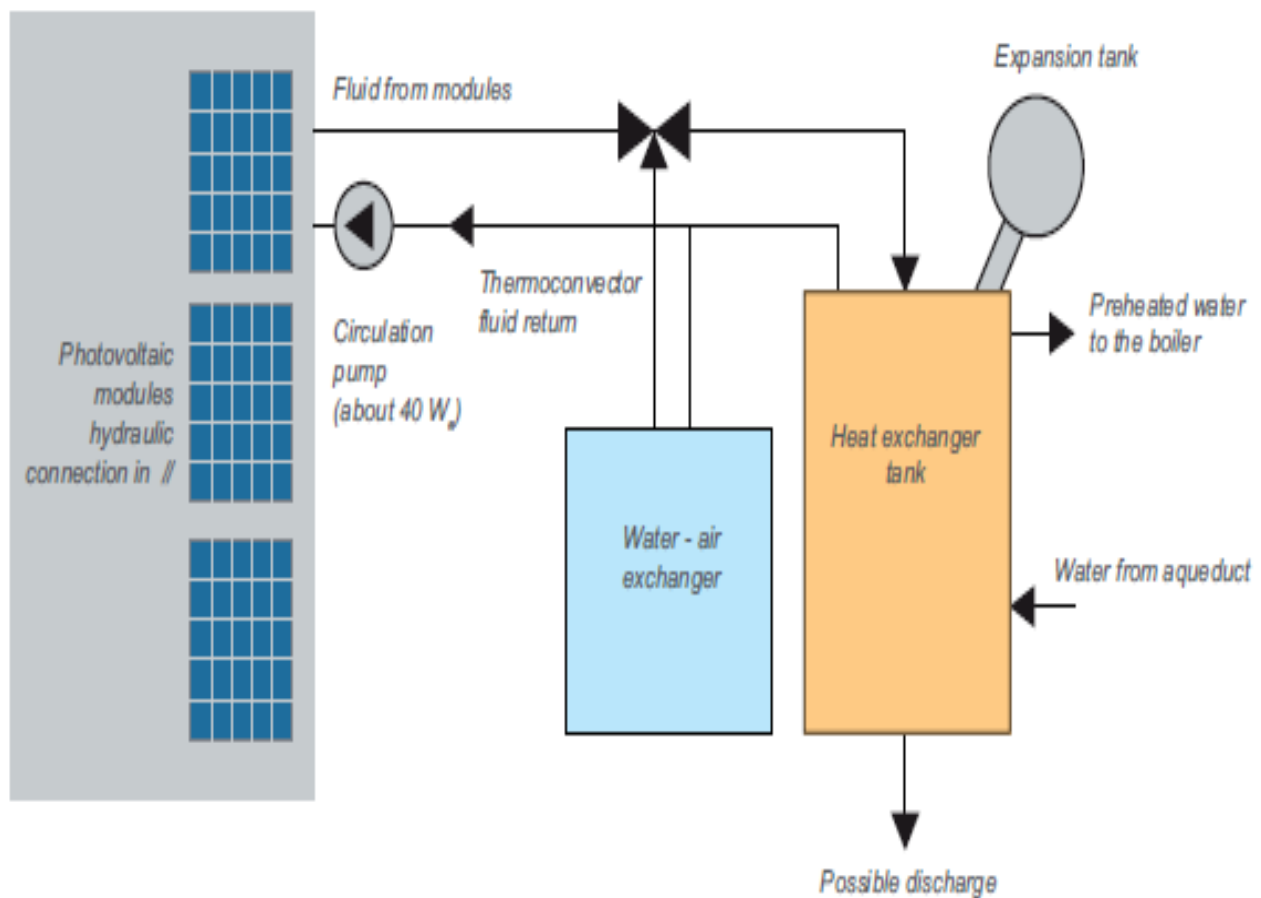


Figure 4.7 Photovoltaic - thermal system main components

Note:

Results and calculations will be created and discussed in the second project.